Design of a Wireless Sensor Network to Detect Car Accidents on Highways

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***Abstract*— In Latin America, the number of car accidents are alarming figures every year. Ecuador is one of the countries that leads the statistics. This paper presents an engineering design proposal to detect a car accident on roads or highways with the aim to reduce deaths caused by these events and to improve the response time of the corresponding emergency entities. This work analyzes a particular scenario and does not pretend to compare the performance of our proposal with prior related works. Our solution consists of several components: a wireless sensor network with elements based on open source tools (such as Arduino nano microcontroller), distance sensors (HC-SR04) and accelerometer sensor (MMA7361), a Raspberry PI 3 model B embedded system and the deployment of a Zigbee network. The system is connected by means of a wireless local area network (WLAN) to a database server and a web application. Sensors response (accelerometer and proximity) in a frontal vehicle collision was proven by implementing a prototype, in order to be tested in a real scenario. The numerical results demonstrate that the response time between the vehicle and the concentrator affects (either increasing or reducing) the total communication time between the vehicle and the web server.**

Keywords— Intelligent Transportation Systems, Internet of Things, Telematics, Wireless Sensor Network

I. Introduction

In 2014, Ecuador topped the list of car accidents in the Latin American region according to the Federation Internationale de l'Automobile (FIA) with a high vehicle accident rate, over 17 people killed per 100,000 inhabitants. The lack of traffic controls and misconduct of drivers are safety problems to face. These problems are often detected in provinces either from the highlands or the coast around the country. Statistics provided by the National Traffic Agency of Ecuador, indicate that almost 30,269 traffic accidents occurred nationwide during 2016. The first trimester of 2017, a total of 7,123 automobile accidents were registered. From this total, 3,687 corresponded to accidents where a type of collision was involved, e.g., side impact, crashing, rear impact, friction, frontal collision, among others Fig. 1.

Other approaches focus on the use of a smartphone with GPS and accelerometer features to alert emergency secretariats about road accidents [1][2] . Their main goal is to use the devices to detect crashes produced at low speed.

Wireless sensor network is a field of study currently growing and rapidly evolving due to the great interest aroused in recent years. This is a new concept in both data acquisition and processing, closely related to the Internet of Things (IoT) paradigm. Applications are very diverse, from the industrial automation to commercial, agricultural, residential, transportation, as well as its use in smart cities to measure different variables, providing a friendly environment and sustainable economic growth.

The scenario of study corresponds to an area without GSM coverage located on roads that connect different towns. Wrong deployment of antennas, high density of either population or vegetation and physical issues that influence on the efficient coverage (i.e., weather conditions) or high interference areas (due to valleys, hills, trees) are factors that contribute to diminish cell coverage. An open source prototype was proposed to detect car crash accidents in areas without GSM coverage [3]. This approach used open source because the flexibility, customizability and low cost.

In this paper, the data is acquired by sensors and analyzed to determine thresholds that each sensor variable takes during a collision. We develop a protocol to allow the data packets exchange between the prototype nodes. Then, the data is converted and sent to the system user, the web platform and a log registering an alert about new accidents. Finally, an overview of the required adjustments for the prototype to work in a real scenario is presented.

The rest of this paper is organized as follows: Section II presents a brief description of the system design; Section III describes the robustness of the components used in the prototype; Section IV presents results analysis obtained from the captured data of sensors installed inside the prototype car.

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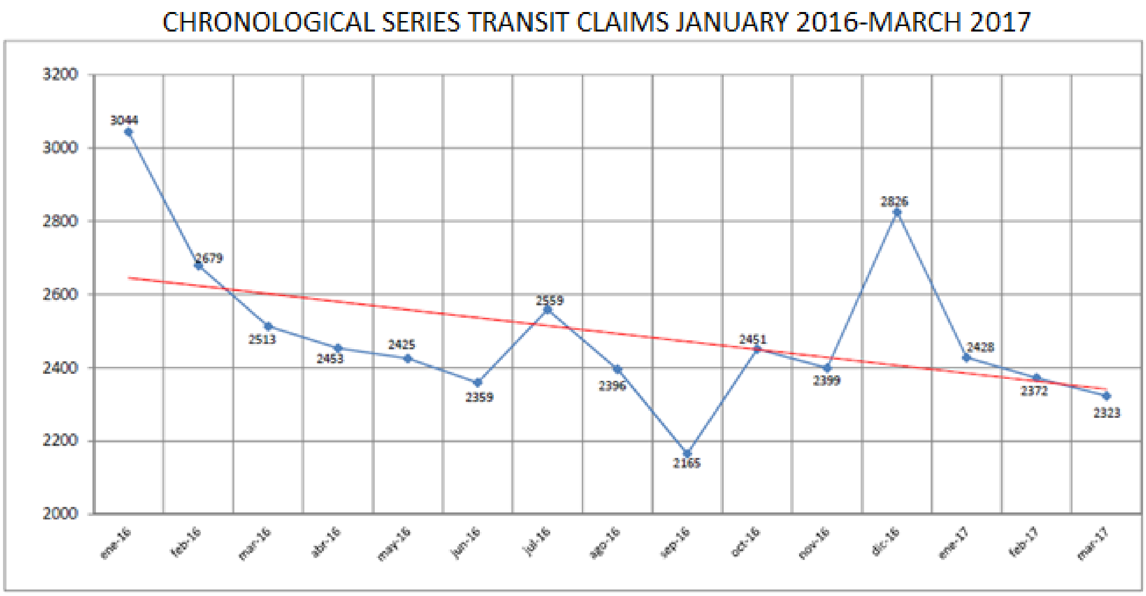

Fig. 1 Chronological series of traffic accidents, January 2016 to March 2017

Finally, Section V concludes the paper and presents future improvements that can be made to the prototype deployed.

II. System Design

The sensor network is based on an ad-hoc network architecture with a client-server model. The main components of the architecture are the sensors, the nodes and the network (GSM or WLAN) through which the database server communicates with the nodes. In addition, the database server with the web application allows users to manage information collected by sensors. Fig. 2 depicts the elements of the proposal. The first block consists of sensors and a concentrator, while the second block consists of the database server and the web application. The information flow starting from data collected by sensors and conveyed through the wireless network to connect the information between the database server and the web application is depicted in Fig. 3.

Both hardware and software integration allowed the prototype to work with two antennas to cover a GSM sector. When vehicles crash in an area where antennas arrays do not provide GSM coverage, data acquisition by sensors is conveyed to the concentrator. Once the concentrator detects an accident based in algorithm, data packets are conveyed to different concentrators in the network until reaching a connection with the nearest base station. Finally, the package is sent through the GSM network to the database server. The information can be displayed through a web application [4].

A. Model entity relationship of the database

Because large amounts of data collected by sensors are handled, they should be modeled and gathered for both ease and fast access. Therefore, it was decided to implement a data structure which is divided into four relational tables that represent real-world entities with their respective attributes. The design of the database consists of four main entities: Node, Accident, Driver and Vehicle.

B. Web Application

The website was developed using personal computers. It was enabled port 9000 to access the main page. The website contains important sections detailed as follows:

1) Start screen.

When someone accesses the web application, a welcome screen is displayed, depicting the status of the current monitoring with the message "We are currently monitoring the status of the nodes from our application". Fig. 4 shows the initial screenshot.

2) Real-time notification

This pop-up element appears in real time when a crash occurs, displaying the message: "Warning of a new crash" followed by an access to "Verify Accident". Selecting the access, automatically will be redirected to the window of the last accident registered to verify the event record. Fig. 5 depicts the real-time notification screenshot.

3) Last registered accident

This window let to know firsthand information about the last car accident. It is possible to access through the main menu or immediately after a vehicle accident occurs. Fig. 6 depicts a screenshot of recorded accidents.

III. Robust wireless network architecture

For the system deployment the prototype should be adapted to a real scenario. Antennas and routers that meet the requirements will be defined, as well as the distance between nodes, among other aspects. It has to be considered variables that could affect the GSM network performance, e.g., coverage loss due to the density of either users or vegetation. A network that presents losses, generates decay in GSM services [5][6]. For this reason, a deployment of broad range antennas is considered. To supply the needs of this scenario, it is possible to deploy Yagi antennas since the scope of their coverage on sections in the best cases reach near 30 km. In addition, a router with GSM

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communication is located in an area with enough coverage. After considering the type of antenna, it is necessary to provide an improvement of the prototype [7].

One purpose is to take advantage of the prototype and to integrate it into a communication structure usually found on roads, covering inaccessible places. The robustness of the components to be used is detailed below.

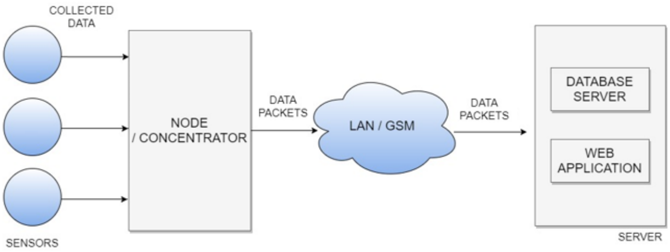

Fig. 2 : Architecture of the wireless sensor network

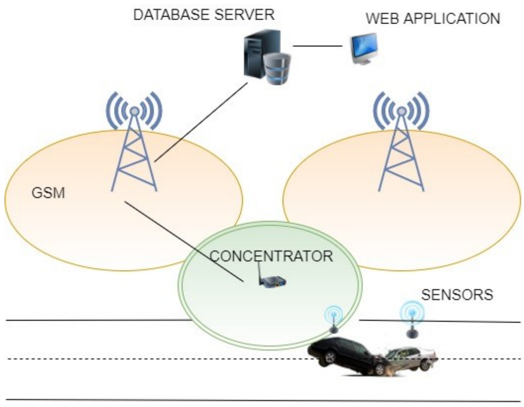

Fig. 3: Parties involved in the flow of information

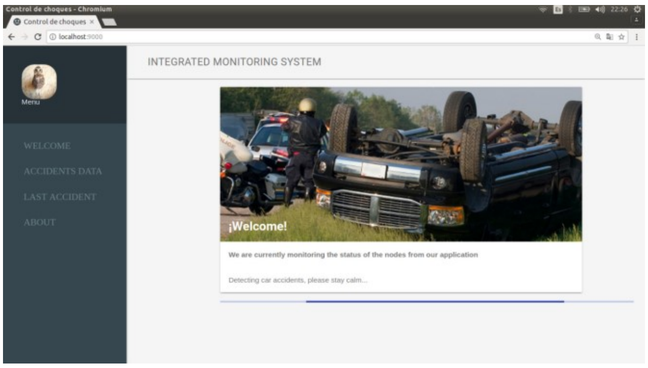

Fig. 4 : Welcome screenshot

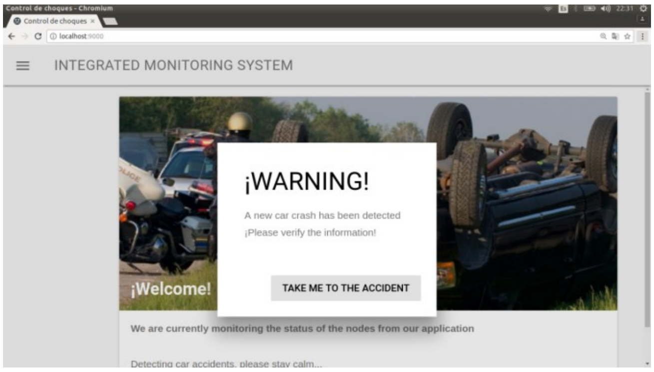

Fig. 5 : Real-time notification pop-up.

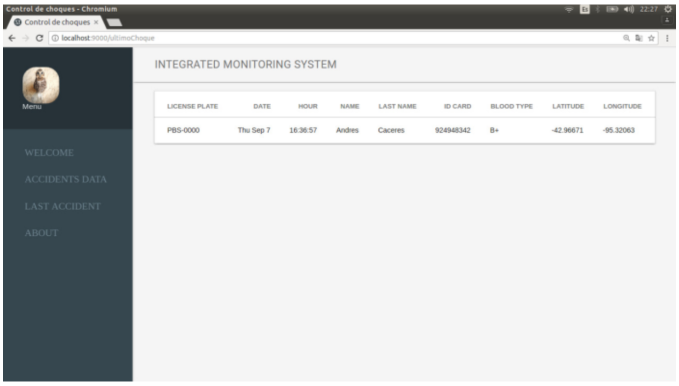

Fig. 6 : Log of accidents

- MikroTik RB912UAG-2HPnD. Device used as interpreter. It works with 64 MB of RAM and a storage of 128MB. It handles a Wireless 2.4 GHz AR9342 standard 802.11b / g / n chip with MCS7 transmission of 24 dBm, -73 reception sensitivity to 251 mW transmission power.
- AirMax sector AM-2G15-120. Antenna with opening angle of 120 degrees, for outdoor environments. It works in the frequency of 2.4GHz with a gain of 15dBi. It has an interface for SIM card with 3G support with a 3g miniPCIe card for GSM support.
- Phocos CMLmppt 10A. Device with a temperature control to manage the charging algorithms in relation to the maximum use of solar panels, connected and managed through software. It is complemented in both 12V and 24V by an automatic voltage detection system. LEDs show the battery charge and notify when it is low voltage.
- Yingli Solar Series YGE 72 Cell. High-tech solar panel. It contains high transmission glass and has a unique anti-reflective layer that allows to direct more light to solar cells, with a maximum delivery of 15A and supports a temperature of 85 degrees Celsius.

To assess an effective network coverage, the concentrator should be located every 50 kilometers. Each concentrator provides a radial coverage at an angle of 120 degrees, locating

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them at 30 kilometers from the distant points. The ideal distance at the midpoint to guarantee coverage area is 15km. Fig. 7 depicts coverage radio and the ideal distance in which the nodes should be located [8].

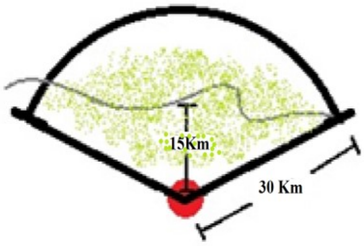

Fig. 7 : Amplitude of the coverage area

Each point of the antennas represents the architecture of the ZigBee network with its concentrators. It means that in each station will be located a concentrator connected by GSM to the server. Fig. 8 depicts in detail the components of the robust network and its form of communication [9].

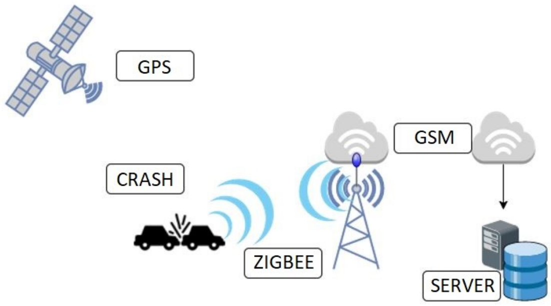

Fig. 8 : Robust network diagram

IV. ANALYSIS OF RESULTS

This section presents the tests results for the prototype performance. These results demonstrate the ability to accurately detect crashes and the coverage analysis.

A. Overview of the test environment

Configuration, assembly and collision detection experiments of the prototype were carried out at a college campus using microcontroller tools as Arduino, complemented with distance sensors (HC-SR04), and accelerometer (MMA7361), Raspberry PI model B embedded system with Raspbian operating system. Samsung laptop with core i5 running Linux Ubuntu with a MySQL database manager system and HTTP server with Node.js. The data collected by sensors were downloaded and analyzed in a spreadsheet. The connectivity analysis according the distance was performed empirically evaluating the reception of packets varying the distance. This last test was carried out in a curve road of 500 meters [10][11].

B. 4.2. Empirical results of the sensors

To detect a crash was necessary to carry out empirical tests, in which the data from sensors were sent to be subsequently evaluated. Since sensors were installed inside the prototype car, they experience the same forces that are manifested inside a vehicle, in order to identify what happened during the accident. Accelerometer sensors measure the acceleration experienced during a sudden brake [12]. Acceleration reduction in the three axes is an indicator of the force induced to the device due to the crash as the car reaches a sudden stop. The Fig. 9 depicts the behavior of different axes that make up the accelerometer as the prototype advances until colliding with another vehicle. It is observed peaks around 10 centimeters of distance, the same as the trigger when detecting the crash. Before this measurement, we observed how sensors vary independently because both the prototype and the installed sensors were in movement [13]. During this period, there are also much smoother peaks than the ones presented at the moment of a crash. Fig. 9 represents the axes of the accelerometer sensors x, y, z which are yellow, green and blue respectively while Fig. 10 represents the distance sensor.

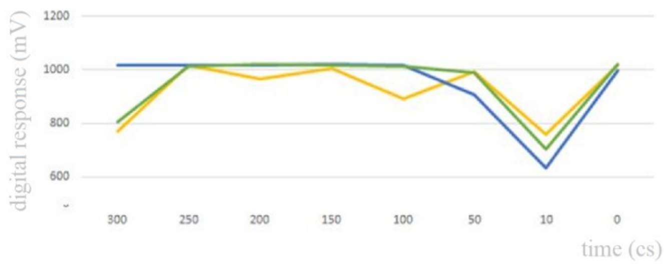

Fig. 9 : Accelerometer response due to a collision

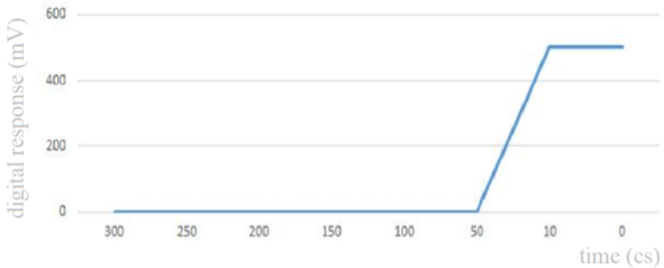

Fig. 10 : Response of ultrasonic sensor due to a collision

By joining sensors responses, the scenario where a collision occurs can be defined, i.e., when a distance fewer than 10 centimeters is taken opposite an obstacle and when the accelerometer abruptly changes values being below the number 800 mV.

C. Analysis of coverage versus distance

To verify the coverage range of the prototype in a real environment, connectivity tests were carried out within the scenario indicated previously. Tests allowed to measure system coverage empirically as distance varied (the prototype moved away from the receiving antenna) [14]. For these tests, an algorithm was developed to send data frames sequentially and without interruption [15][16]. Once it stopped receiving data

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frames, communication between the prototype and the server had stopped. Fig. 11 depicts the path traveled, as well as the referential points (green icons with dot) in which distance was recorded from the reference point of departure (green icon with checkmark). The point where connection was lost is represented with a red icon.

Fig. 11 : Test path

ID	GPS COORDINATES (GMS)	DISTANCE [m]	COVERAGE
1	S 2° 8' 43.571'';O 79° 57' 47.395''	0	YES
2	S 2° 8' 42.169''; O 79° 57' 47.395''	98	YES
3	S 2° 8' 40.823''; O 79° 57' 45.637''	165	YES
4	S 2° 8' 38.201''; O 79° 57' 42.67''	295	YES
5	S 2° 8' 37.659''; O 79° 57' 39.951''	357	YES
6	S 2° 8' 40.56''; O 79° 57' 37.836''	480	NO

Fig. 12 : Coverage versus distance

When carrying out these tests, a certain delay could be noticed while sending packages starting from ID 4 as depicts Fig. 12, a delay that could be verified it was 3 seconds on average. However, this delay time was negligible compared to the average reaction time of a person to make an emergency call in case of an accident [17] [18].

V. Conclusions

An open-source solution prototype was proposed that is able to detect and alert car accidents in roads and highways saving implementation costs. The appropriate network topology is centralized, involving multiple clients or nodes that communicate to a database server. The data is collected by sensors at the moment of the accident making possible to understand better crashes behavior and quantify them.

As future work, the data analysis can be used to find trends or patterns in vehicular accidents, such as peak hours where accidents occur, types of vehicles that cause it, repeat offenders, among others. We also will investigate the use of microcontrollers to decrease system error in order to detect an event related to collision between vehicles. Finally, if there are two vehicles equipped with sensors, two collisions will be recorded in the same geographical coordinates. An algorithm that discriminates one of the two collisions at random can be created. However, it is recommended that both are recorded, since eliminating one of them would affect the log and there would not be consistency in data analysis.

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